Enabling Multi-Constellation Advanced Receiver Autonomous Integrity Monitoring (ARAIM)

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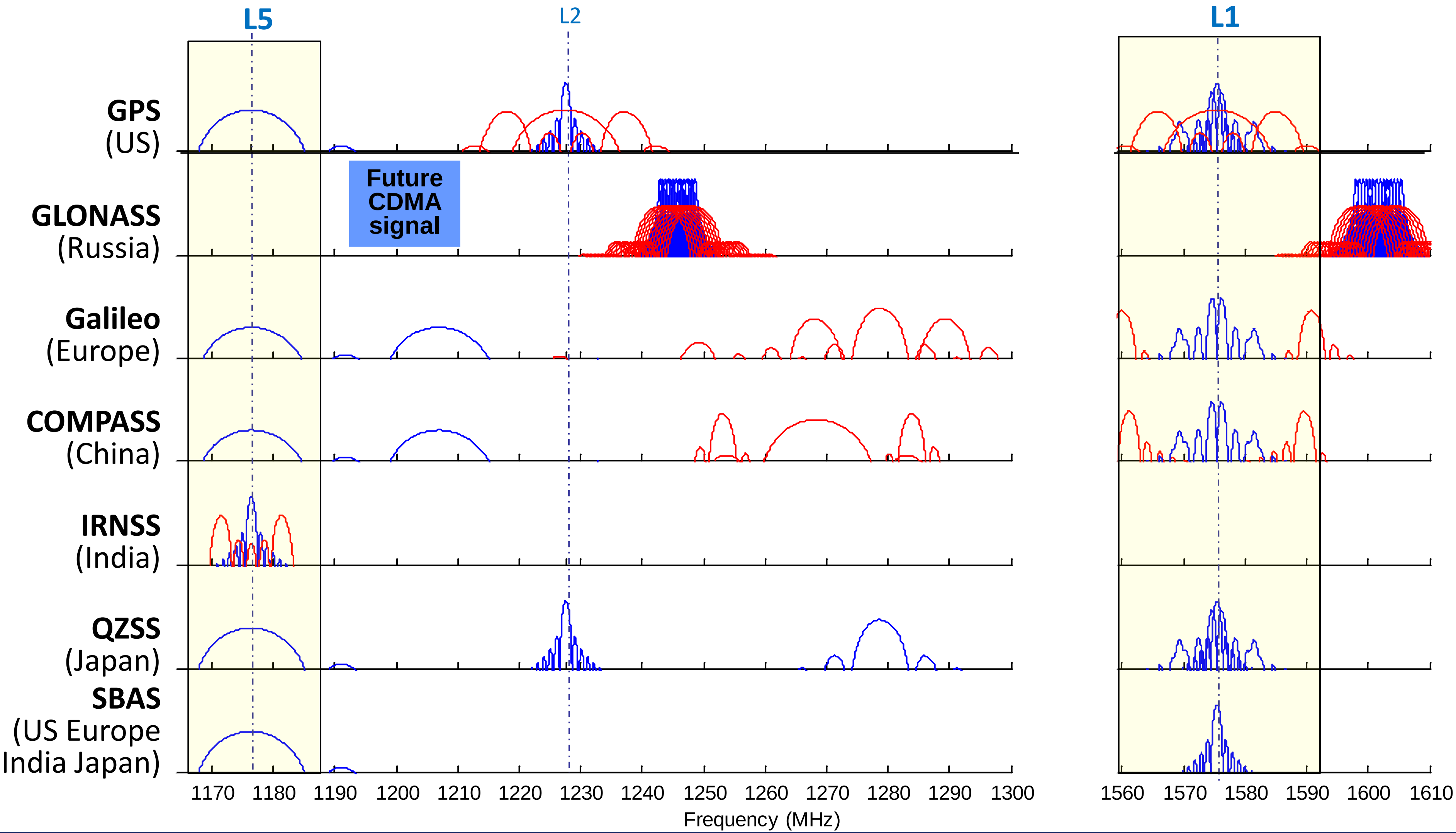
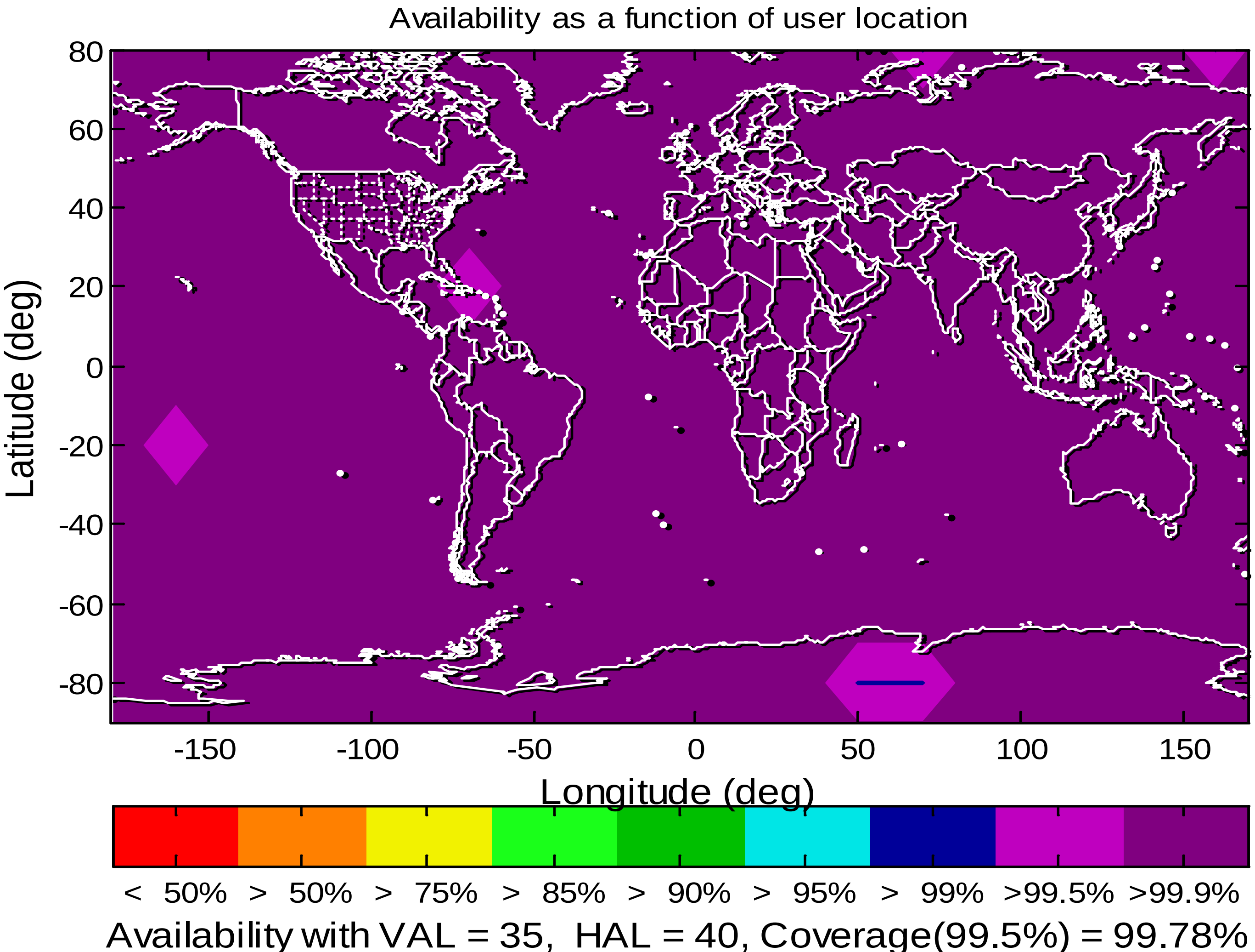
ARAIM Overview

- **GNSS Evolutionary Architecture Study (GEAS) Phase II Report Recommendations**
  - Implementation of dual frequency SBAS
  - Development of architectures and algorithms for Advanced Receiver Autonomous Integrity Monitoring (ARAIM), based on
    - Dual frequency ARNS (L1 and L5) signals
    - At least two independent GNSS core constellations for civil aviation.
- **GEAS determined ARAIM could enable worldwide LPV-200 performance, provided:**
  - Measurement redundancy and geometric diversity are assured
  - Performance of specific parameters for the core GNSS constellations are assured

Current International Signal Plans



Dual Frequency ARAIM
With 27 GPS + 27 Other GNSS



Allow other constellations..

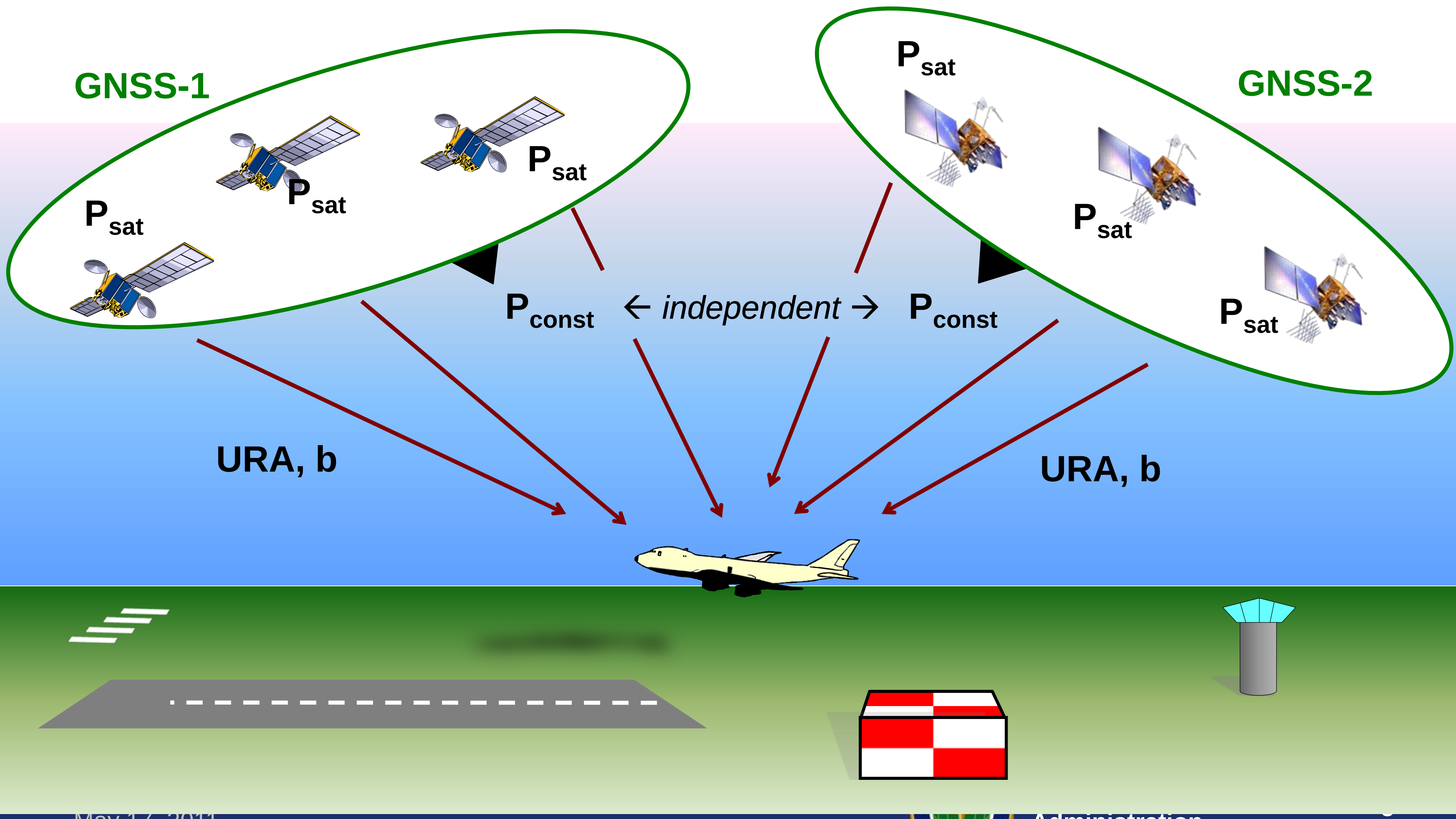
Robust to weak constellations?

URA = 1m

P_{sat}=10^{-3}

P_{const} = 10^{-6}

ARAIM Parameters



Integrity Support Message Parameters

- User Range Accuracy → **'URA'**
  - Standard deviation of the overbounding Normal distribution for signal-in-space errors
- Bias parameter → **'b_{max}'**
  - May be needed to bound potential non-zero mean error distributions
- Fault state probability (fault-rate × time-to-notify) → **'P_{sat}'**
  - Needed for faults that ***are*** independent between satellites
- Probability of constellation-wide fault → **'P_{const}'**
  - For multiple faults that are ***not*** independent between satellites
    - Example is Earth Orientation Parameter (EOP) fault undetected by GNSS ground system

Worldwide Coverage Sensitivity

27 GPS + 27 Other GNSS

less accuracy (URA) →

Less constellation reliability ↓

Less satellite reliability ↓

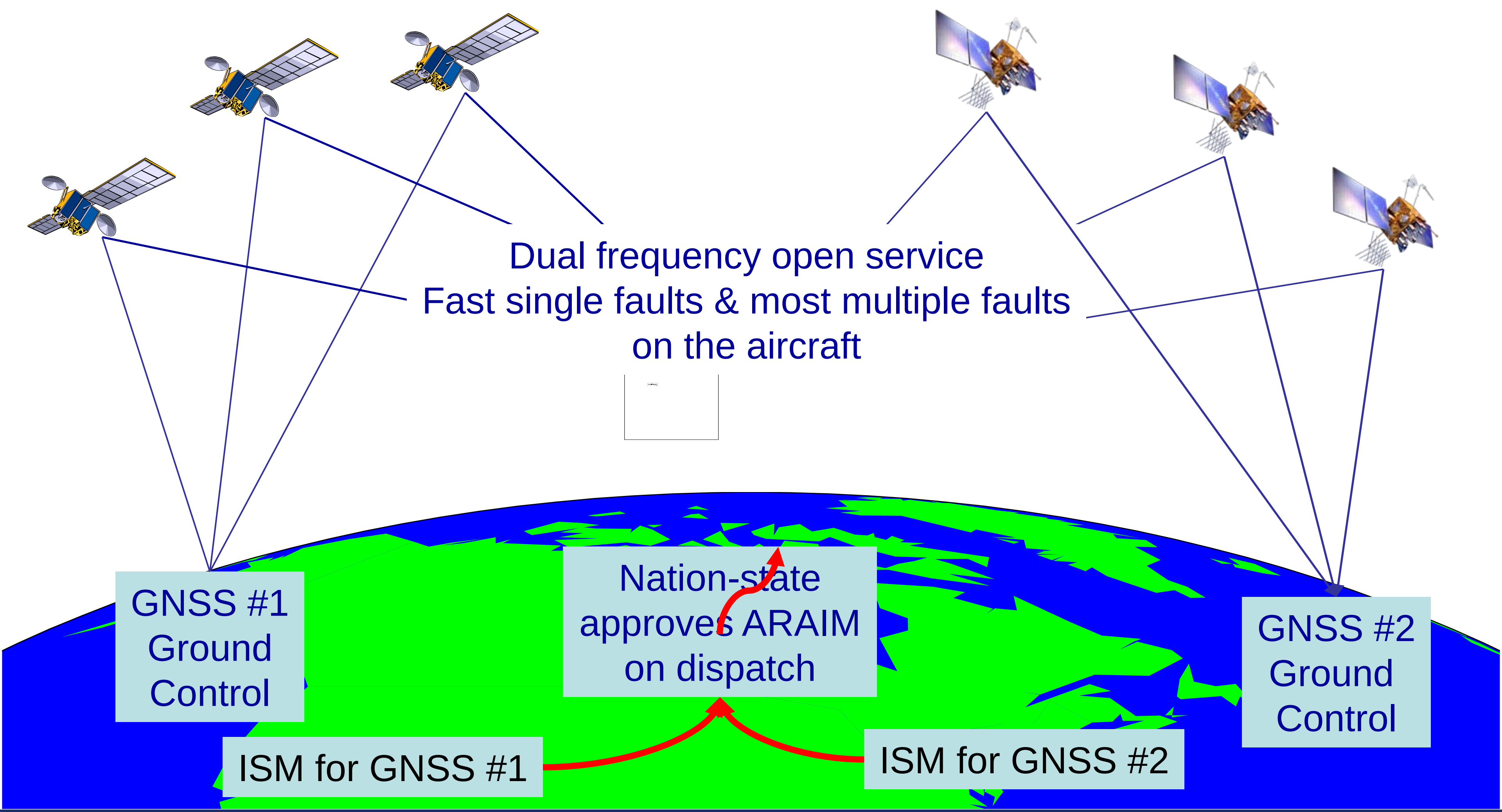
P_{const}	P_{sat}/URA	.5 m	1 m	1.5m	2 m	3 m	3.5 m	4 m
$P_{const} < 10^{-8}$	10^{-5}	100%	100%	100%	100%	100%	42.9%	3.4%
	10^{-4}	100%	100%	100%	100%	100%	0	0
	10^{-3}	100%	100%	100%	99.6%	6.6%	0	0
$P_{const} = 10^{-6}$	10^{-5}	100%	100%	95.0%	51.5%	0	0	0
	10^{-4}	100%	100%	95.0%	51.5%	0	0	GPS?
	10^{-3}	100%	100%	95.0%	51.3%	0	0	0
$P_{const} = 10^{-4}$	10^{-5}	100%	98.5%	79.2%	0.1%	0	0	0
	10^{-4}	100%	98.5%	79.2%	0.1%	0	0	GPS?
	10^{-3}	100%	98.5%	79.2%	0.1%	0	0	0

P_{sat} = Prob. of satellite fault

P_{const} = Prob. of constellation fault

b = 0.75 m

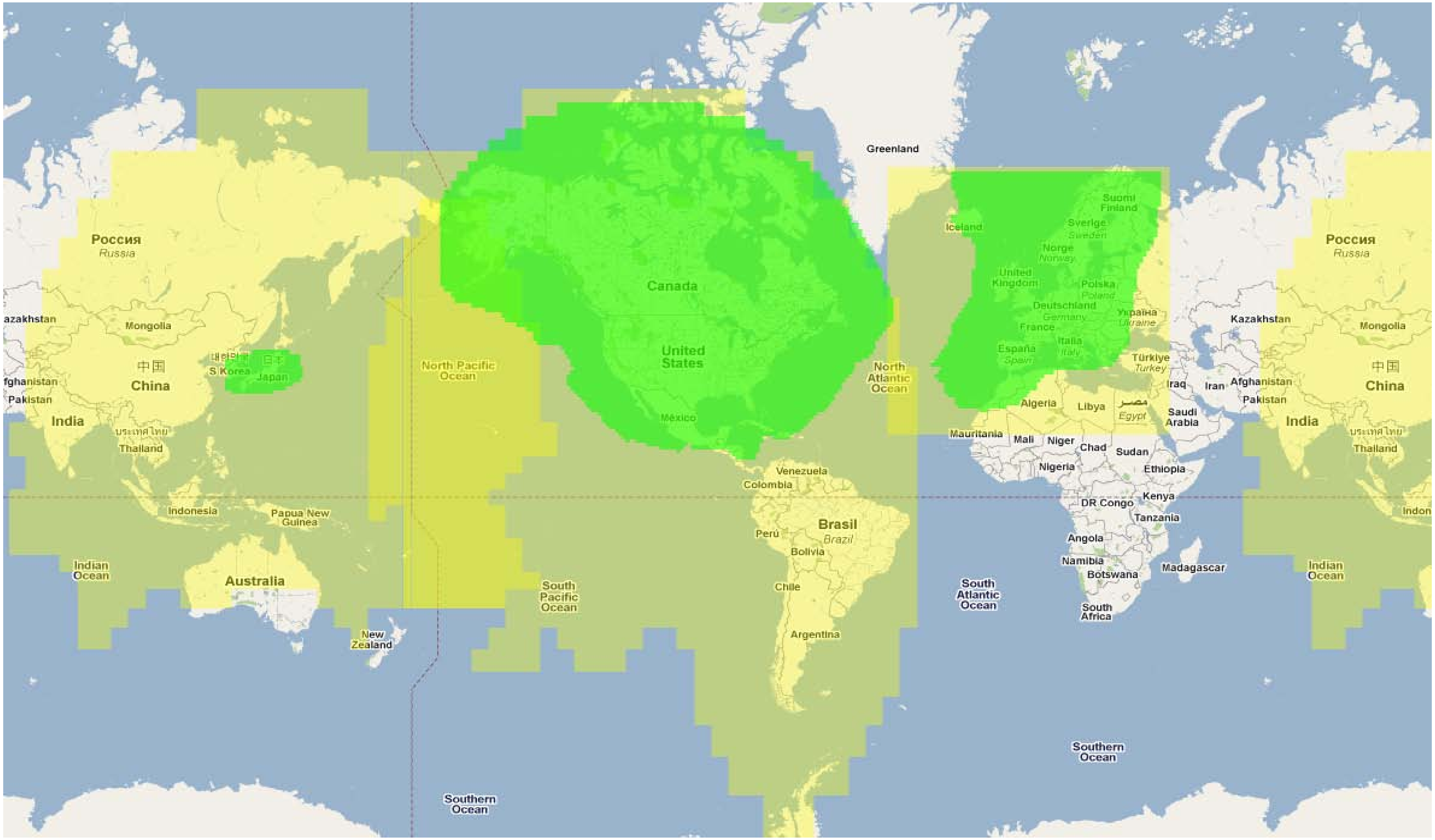
Integrity Support Message (ISM)



Multi-Constellation GNSS Operational Considerations

- **Will use of the host GNSS be required for flight in the host region?**
  - GLONASS required to fly in Russia?, Galileo in Europe?, Compass in China?
  - GPS universally accepted as second GNSS constellation?
  - Pick any Two GNSS Constellations?
- **Who will compute and assure the ISM?**
  - GNSS service provider broadcast on core integrity channel?
  - SBAS/ARAIM service provider and regulatory authorities for the applicable sovereign national airspace?
- **Geodetic reference frame alignment considerations**
  - 3 dimensional waypoint for LPV-200 approaches using multi-constellation ARAIM

Combined SBAS Snapshot



SBAS with ARAIM

- **SBAS GEOs can provide corrections and monitoring to keep the URE and fault-free UDRE small**
- **SBAS can identify and eliminate common mode threats such as EOP**
- **ARAIM can extend the required TTA and handle some multiple fault cases for SBAS**
  - Must meet low probability for TTA used by ARAIM
- **SBAS then mainly needs to assure the fault-free performance**
  - Easier than 10^{-7} integrity within 6 sec.

URA Commitments

- **Is it likely GNSS providers will commit to URAs of .25 - .5m in their performance standards ?**
  - Commitment of .25m would typically mean that nominal performance was ~.06 (4:1 margin)
- **Should the L5 SBAS/ARAIM signal also include corrections to assure URAs to the desired level ?**
  - Avionics-based ARAIM detection of fast *clock* faults
  - Avionics-based 2RF estimation of *ionosphere* delays
  - Long term corrections and UDRE for *ephemeris* errors

Multi-Constellation SBAS w/ARAIM Implementation Considerations

- **Dual frequency GNSS minimum user for ARAIM**
- **Universal SBAS message set is needed with room for growth**
  - PRNs for all global and regional GNSS
  - PRNs for all existing and planned SBAS
  - Sufficient margin for growth
  - Ensure *all* PRNs useable to avoid mistakes from L1 experience
  - SBAS providers should have latitude to augment all GNSS if desired
- **If Multi-constellation timing offset corrections are be needed**
  - To what time reference will the offsets be aligned?

Potential SBAS PRN Mask

L1 SBAS SARPS	Current		L5 Allocations	Maximum
GPS	38		GPS (Current)	63
GLONASS	24		GLONASS	63
			Galileo	63
			Compass	63
			QZSS	5
			RNSS	5
Spare	57		GNSS Growth	17
Total GNSS/Other	119		Total GNSS/Other	279
SBAS	19		MSAS	5
			WAAS	5
			EGNOS	5
			GAGAN	5
			SDCM	8
Spare	72		SBAS Growth	17
Total SBAS	91		Total SBAS	45
Total PRNs	210		Total PRNs	324

Summary

- Four basic parameters are needed to enable ARAIM
- A common understanding of these parameters must be developed and agreed upon by the service providers for interoperability
- GNSS service providers need to include these parameters in Performance Standards
- ISM is a mechanism to deliver these parameters to users
- Delivery of ISM could be from multiple sources
- SBAS needs a strategy to broadcast ISMs for Multi-Constellation